L.3: High energy electron beam from sub-mm size laser-plasma accelerator

Laser driven plasma based accelerator uses relativistic electron plasma wave for acceleration of electrons. The plasma wave is excited in the wake of an ultra-intense, ultra-short laser pulse propagating in a plasma medium. Typically, the amplitude of the accelerating electric field associated with the plasma wave is ~ 100 GV/m. The electrons injected in to such high field may be trapped and accelerated to 10s of MeV over sub-mm length. As the injection of electrons in to the plasma wave from external source poses many practical difficulties, electrons are invariably self-injected (injected from the plasma itself) in to the plasma wave in most of the experiments. The self-injection occurs beyond certain threshold amplitude of the plasma wave, which depends on various laser and plasma parameters. Acceleration of self-injected electrons in the early experiments had produced electron beam with poor quality (divergence ~ 100 mrad and energy spread ~ 100%). The major breakthrough has been achieved in year 2004 when mono-energetic electron beam was first produced and the field has progressed rapidly since then. In our recent experiment *[RRCAT Newsletter 22(1) p.10, 2009]* we had shown that high quality electron beam with divergence ≤ 10 mrad and energy spread ≤ 10% could be produced over a narrow range of plasma density. In that experiment, the acceleration was achieved up to 21 MeV, which was limited by the amplitude of the plasma wave and the dephasing length, $L_d \propto n_e^{-3/2}$. To increase the energy of electron beam, it is necessary to self-inject plasma electrons and accelerate them at reduced plasma density. This requirement demands higher laser intensity. One way to do this is to have a higher power laser and the other way is by using focusing optics with lower f number to reduce the size of focal spot. We have used the second route.

In the present experiment, a table top 10 TW laser was focused to spot size of 9 μm (Half Width at e^{-2} of Maximum), as shown in Fig. L.3.1. The spot encloses 55% of energy resulting in peak intensity of 2.4×10^{18} W/cm^2. The electron acceleration was performed with the set-up as described earlier *[RRCAT Newsletter 22(1) p.10, 2009]*.

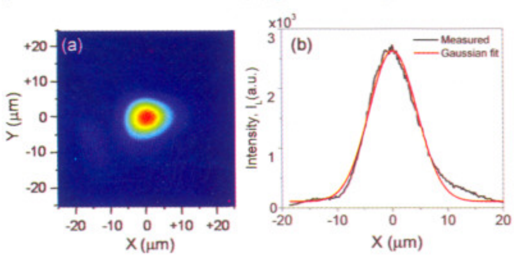

Fig. L.3.1: Intensity distribution at the focus : (a) 2D image of the focal spot, (b) Intensity profile of the focus along a horizontal line at Y=0

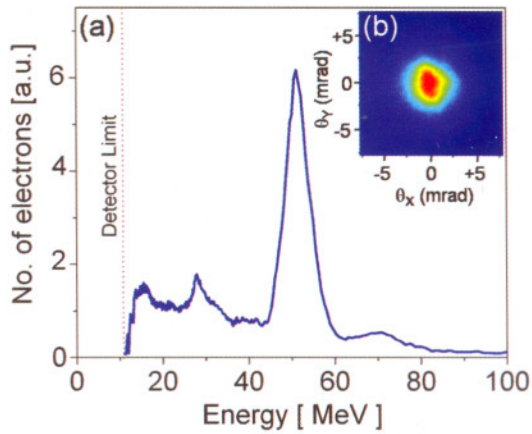

Fig. L.3.2: Well collimated mono-energetic electron beam at 50 MeV. (a) Energy spectrum of the mono-energetic electron beam produced at plasma density of 6.5×10^{19} cm^{-3}. (b) Spatial profile of the electron beam

After careful optimization of the experimental conditions, accelerated electrons were detected at a lower plasma density as compared to the earlier experiment. A well collimated electron beam with divergence < 10 mrad was observed to occur at a plasma density around 6.5×10^{19} cm^{-3}. Energy measurement of this beam revealed that it is mono-energetic and the peak energy is as high as 50 MeV as shown in Fig. L.3.2. The energy spectrum also has a tail extending beyond 80 MeV, as seen in the Fig. L.3.2. In addition to the higher energy, the collimated beam could be clearly seen without background electrons of large divergence which was observed in earlier experiment. The length of the plasma medium was measured from the image of the plasma which was recorded with a CCD camera and an imaging lens that collected the Thomson scattered laser light from the plasma electrons. The typical length thus obtained was ~ 500 μm. The high energy of the electron beam could be produced primarily due to relatively higher intensity of the laser. However, change in size of the focal spot and the background plasma density would also play significant role in laser pulse evolution while propagating in plasma, thereby influencing the injection and acceleration mechanism, as seen in simulations. The pulse evolution is further complicated with the presence of pre-plasma due to pre-pulse pedestal before the main 45 fs laser pulse. It was observed in this experiment that the length of the plasma, its structure, and the electron beam parameters changed from shot-to-shot. Preliminary observations indicate that one of the causes for this variation is the pre-pulse whose intensity is found to change from shot-to-shot. Future studies will be aimed to improve the stability of the electron beam.

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